# PERFORMANCE ANALYSIS OF ALUMINIUM OXIDE/POLYALKYLENE GLYCOL NANOLUBRICANT IN AUTOMOTIVE AIR CONDITIONING SYSTEM

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**SUPERVISOR'S DECLARATION**

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the degree of Doctor of Philosophy.

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**STUDENT'S DECLARATION**

I hereby declare that the work in this thesis is based on my original work except for quotations and citations which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

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# ABSTRAK

Penjimatan tenaga dan peningkatan kecekapan bahan api akan mengurangkan kebergantungan kepada bahan api fosil. Salah satu pendekatan untuk mempertingkatkan kecekapan bahan api dan seterusnya penjimatan tenaga adalah dengan meningkatkan prestasi sistem pendingin hawa otomotif (AAC). Sistem AAC adalah satu beban tambahan terbesar pada kenderaan; melalui peningkatan beban tambahan oleh sistem AAC akan menurunkan kecekapan, meningkatkan penggunaan bahan api dan meningkatkan pengeluaran gas rumah hijau. Persekitaran dunia yang semakin panas dan kesan El-Nino akan meningkatkan penggunaan AAC. Salah satu pendekatan terbaru yang dapat meningkatkan kecekapan AAC adalah melalui penggunaan partikel bersaiz nano ke dalam sistem penyejukan. Objektif kajian ini adalah untuk menilai dan mengoptimumkan prestasi sistem AAC dengan menggunakan nano pelincir Aluminium Oksida/Polialkalina Glikol ($Al_2O_3$/PAG). Ini boleh dicapai dengan menstabilkan dan mencirikan nano pelincir $Al_2O_3$/PAG, menyiasat prestasi serta penggunaan tenaga relatif dan; akhirnya mengoptimumkan parameter operasi sistem AAC. Nano pelincir $Al_2O_3$/PAG disediakan melalui kaedah dua-langkah dan kestabilan partikel nano dinilai menggunakan beberapa kaedah analisis. Seterusnya, sifat-sifat terma fizikal nano pelincir $Al_2O_3$/PAG disiasat untuk kepekatan sehingga 1.0% dan suhu kerja bermula daripada 30 hingga 80 °C. Sifat-sifat tribologikal nano pelincir $Al_2O_3$/PAG sehingga 0.3% kepekatan juga dinilai. Prestasi dan penjimatan tenaga AAC dinilai dengan kelajuan pemampat dalam julat 900–2100 rpm, caj awal bahan pendingin antara 90 ke 170 g dan dengan kepekatan bermula 0.006 hingga 0.014% nano pelincir $Al_2O_3$/PAG. Prestasi AAC dinilai dengan menentukan keupayaan penyejukan, kerja pemampat, dan pekali prestasi (COP). Sementara itu, penjimatan tenaga adalah diukur dari penggunaan kuasa. Pengoptimuman parameter AAC adalah dilakukan dengan bantuan perisian statistik melalui analisis ANOVA bagi menentukan kepentingan dan mengaitkan hubungan antara faktor-faktor yang dikaji. Pendekatan "desirability" telah digunakan dalam menentukan keadaan optimum faktor-faktor dan tindakbalas. Kekonduksian terma dan kelikatan adalah meningkat dengan peningkatan kepekatan tetapi menurun dengan suhu. Penilaian tribologi mendapati bahawa pelincir nano $Al_2O_3$/PAG dengan kepekatan 0.010% mencapai keadaan optimum melalui pekali geseran (COF) dan kadar haus terendah. Daripada sifat terma fizikal dan tribologikal, penilaian prestasi AAC dan penjimatan tenaga dilakukan sehingga kepada kepekatan 0.014% sahaja. Keputusan akhir menunjukkan bahawa peningkatan COP tertinggi adalah 31.46% dengan nilai purata 17.42% dicapai. Manakala penjimatan tenaga tertinggi adalah 23.89% dengan nilai purata 11.38%. Nilai COP dan penjimatan tenaga adalah tertinggi apabila kepekatan 0.010% digunakan. Pengoptimuman parameter seperti pemampat kelajuan (1167 rpm), caj permulaan (170 g) dan kepekatan (0.011%) telah menghasilkan tindakbalas yang optimum dengan kapasiti penyejukan (1.303 kW), kerja pemampat (14.70 kJ/kg) dan suhu keluar injap pengembangan (4.06 °C) dan penjimatan tenaga (7.12%) dengan nilai "desirability" tertinggi sebanyak 0.819. Oleh itu, dapat disimpulkan bahawa nano pelincir $Al_2O_3$/PAG berkepekatan 0.011% adalah yang paling optimum dan ianya disyorkan untuk digunakan kepada sistem AAC untuk prestasi terbaik. Sistem operasi AAC juga berjalan seperti biasa tanpa ada sebarang masalah semasa kerja-kerja eksperimen dijalankan. Walau bagaimanapun, ujian ketahanan penuh sistem AAC adalah disyorkan untuk kajian seterusnya di mana ianya tidak termasuk dalam skop kajian ini. Generasi baru sistem AAC-teknologi pelincir nano dengan komponen yang lebih kecil dan kecekapan yang lebih tinggi dijangka dihasilkan dalam masa terdekat

## ABSTRACT

Energy saving and fuel efficiency enhancement approach will lessen the reliance on fossil fuel. One of the superlative approaches to enhance the fuel efficiency and eventually saving the energy is by improving the performance of the automotive air conditioning (AAC) system. The AAC system is the biggest supplementary load on a vehicle; extra load employed by the AAC system signifies a decrease in efficiency, increase in fuel consumption and escalates the greenhouse gas discharges. The current hot world weathers and El-Nino affects escalate the use of AAC considerably. One of the novel approaches in increasing AAC's efficiency is by introducing nanoparticles into the refrigeration system. The aim of the present study is to evaluate and optimize the AAC performance and power saving using Aluminium Oxide/Polyalkylene Glycol ($Al_2O_3$/PAG) nanolubricants. This can be achieved by stabilizing and characterizing the $Al_2O_3$/PAG nanolubricant, investigating the performance and relative power consumption and; finally optimizing the operating parameters of the AAC system. The $Al_2O_3$/PAG nanolubricant is prepared by using the two-step method and colloidal stability is evaluated and established by several methods of analyses. Next, the thermophysical properties of $Al_2O_3$/PAG nanolubricant up to 1.0% volume concentrations and 30 to 80 °C working temperatures were investigated. Adding to that, the tribological properties of $Al_2O_3$/PAG nanolubricant up to 0.3% volume concentrations was also evaluated. The AAC performances and power saving were evaluated in the range of 900 to 2100 rpm compressor speed, 90 to 170 g initial refrigerant charge and 0.006 to 0.014% $Al_2O_3$/PAG nanolubricant volume concentrations. The performance of AAC was evaluated by determining the cooling capacity, compressor work, and coefficient of performance (COP). Meanwhile, power saving was evaluated by determining the relative power consumption. The optimization of the AAC parameter was done by the help of statistical tool software employing ANOVA analysis for determining the significant factors and established the relation between the factors. The desirability approach was used in determining the optimal conditions of factors and its responses. The thermal conductivity and viscosity increased with the increase in volume concentrations but decreased with temperature. The tribological properties evaluations found that 0.010% $Al_2O_3$/PAG nanolubricant showed optimal conditions with lowest coefficient of friction (COF) and wear rates were achieved. From the outcome of thermophysical and tribological evaluation, the investigation of AAC performances and power saving are evaluated for up to 0.014% volume concentrations only. The results found that the maximum and average COP enhancements are 31.46 and 17.42%, respectively while the highest and average of power saving attained are 23.89 and 11.38%, respectively. Both COP and power saving was highest when 0.010% volume concentration is used. Consequently, the optimization of the parameter namely, compressor speed, initial refrigerant charge and volume concentrations of 1167 rpm, 170 g and 0.011% respectively yield the optimum responses of cooling capacity, compressor work, expansion valve discharge temperature and power saving of 1.303 kW, 14.70 kJ/kg, 4.06 °C and 7.12% respectively with the highest desirability value of 0.819. Finally, it can be concluded that 0.011% volume concentration is the optimum volume concentration. Hence, it is recommended to use 0.011% $Al_2O_3$/PAG nanolubricant on to the AAC system for the best performance. Nevertheless, full-blown durability run of AAC system is recommended for future work which is not included in the scope of the present study. New generation of nanolubricant technology AAC system with smaller components and higher efficiency is anticipated in the near future.

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## LIST OF SYMBOLS

| | |
|---|---|
| A | Absorbance, |
| b | Path length, m |
| $\beta$ | Ratio of the nanolayer thickness to the original particle radius |
| c | Molar concentration coefficient |
| $\varepsilon$ | Molar absorptivity |
| g | Gravity acceleration, $m/s^2$ |
| h | Enthalpy, kJ/kg |
| k | Thermal conductivity, W/m.K |
| $k_r$ | Thermal conductivity ratio $k_{NL}/k_L$ |
| $m_{RC}$ | Initial refrigerant charge, g |
| $\eta_i$ | Isentropic efficiency |
| $\eta_v$ | Volumetric efficiency |
| $\dot{Q}_L$ | Cooling capacity, kW |
| $\phi$ | Volume concentration, % |
| $\phi_o$ | Initial volume concentration, % |
| $\phi_r$ | Volume concentration ratio, $\phi/\phi_o$ |
| $\varphi$ | Volume concentration in fraction |
| $q_L$ | Heat Absorb, kW/kJ |
| $\rho$ | Density, $kg/m^3$ |
| R | Radius of the particle, nm |
| T | Temperature, °C |
| $\mu$ | Dynamic viscosity, mPa.s |
| $\mu_r$ | Viscosity ratio, $\mu_{NL}/\mu_L$ |
| $\upsilon$ | Kinematic viscosity, cSt |
| V | Sedimentation speed, m/s |
| $w_{in}$ | Compressor work, kJ/kg |
| $\zeta$ | Zeta potential value, mV |

## LIST OF ABBREVIATIONS

| | |
|---|---|
| AAC | Automotive air conditioning |
| AD | Average deviation |
| ASHRAE | American Society of Heating, Refrigerating and Air Conditioning Engineers |
| ANOVA | Analysis of variance |
| ANSI | American National Standard Institute |
| Bf | Base fluid |
| CCD | Center composite design |
| CFC | Chloroflourocarbon |
| CFD | Computational Fluid Dynamic |
| COF | Coefficient of friction |
| COP | Coefficient of performance |
| DOE | Design of experiment |
| EC | Electrical conductivity |
| EDM | Electrical discharge machine |
| EDX | Energy dispersive X-ray |
| EER | Energy efficiency ratio |
| Eff | Effective |
| Eq | Equation |
| Exp | Experiment |
| f | Fluid |
| FCD | Faced Centered design |
| FDC | Fixed-displacement compressor |
| FESEM | Field emission scanning electron microscopy |
| GWP | Global warming potential |
| HC | Hydrocarbons |
| HCFC | Hydroclorofluorcarbon |
| HFC | Hydrofluorocarbon |
| HNBR | Hydrogenated nitrile butadiene rubber |
| HVAC | Heating, ventilation and air conditioning |
| L | Lubricant |

| | |
|---|---|
| l | liquid |
| LPM | Liter per minute |
| MO | Mineral oil |
| NL | Nanolubricant |
| OD | Outer diameter |
| ODP | Ozone depletion potential |
| OT | Orifice tube |
| OT-AD | Orifice tube-accumulator drier |
| P | Nanoparticle |
| PAG | Polyalkylene Glycol |
| PMI | Positive material identification |
| POE | Polyolester |
| r | Ratio |
| RBR | Pure rubber |
| rpm | Revolution per minute |
| RSE | Relative standard error |
| RSM | Response surface methodology |
| SAE | Society of Automotive Engineers |
| SEM | Scanning electron microscope |
| TEM | Transmission electron microscopy |
| TXV | Thermal expansion valve |
| TXV-RD | Thermal expansion valve-receiver drier |
| UMP | University Malaysia Pahang |
| VCRS | Vapor compression refrigeration system |
| VDC | Variable-displacement compressor |
| XPS | X-ray photoelectron spectroscopy |

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